1 Reply to the Editor

Both reviewers indicate that the conclusions of this paper appear counterintuitive, and in contradiction with common knowledge. This does not invalidate the conclusions of the study, but signifies that more analyses and discussions are needed. As reviewer 1 suggests, the authors may have not considered the full range of controls on ET, limiting themselves to a few variables. I would therefore recommend extending the analysis to consider a larger variety of factors, including monthly temperature. Moreover, as both reviewers suggest, more discussion on the processes that may have led to the results of this study are needed.

Response: According to the comments from the two anonymous reviewers, we have revised this manuscript substantially. All revisions are marked as red in the revised manuscript. Please find the revised manuscript in the attachment. The followings are our point-by-point responses to reviewers' comments.

2 Responses to the Reviewer #1

In this paper, the authors attempt to investigate the effects of vegetation change on evatranspiration in shrubland area. Eddy-covariance measurement of three periods' data was analysed. The authors would like to conclude that 1) the cut-off of vegetation increased evatranspiration; 2) the soil evaporation consumes more water than canopy transpiration in this study site. Overall, the authors did lots of work on field experiment and data analysis. The kind of observation and experiment is very important and interesting for hydrologists and land surface modellers to understand the land surface water and energy processes. I appreciate what the authors have done.

Response: Thanks for the positive comments.

But I think the authors have to do more intensified and condense discussion to clarify and support these two main conclusions.

Response: We have revised and condensed the statements of Discussion part and revised the manuscript according to the reviewer's comments. Please see the detailed explanations in the following and the revised manuscript that marked as red.

In the section of "effects of land use change on ET" (4.2), we have deleted the following sentences:

1. "Vegetation coverage gradually decreased during the three periods because of the vegetation cut-off by human activities". Because we think this is repetitive.
2. "annual total ET increased from 375 mm to 478 mm". because we think this might make the reviewers confused.
3. "Li et al. (2009) have concluded that semiarid shrubland may produce more ET only when the vegetation coverage is above a certain threshold. However, when the vegetation coverage is under the threshold, ET might increase, and this finding corroborated the results of our

research". After thinking about the second reviewer's comments, we found we have misunderstood the meaning of this finding of Li et al. (2009), so we deleted this sentence from the Discussion part.

For the first conclusion, the authors compared three years' observed ET data. It was found that the observed ET increased after the cut-off of original vegetation in this study site. But the authors should note that the increase of ET might be caused by several factors. Except for vegetation, meteorological condition is another important influence factor, especially the temperature. From Figure 4, it is clearly shown that from 2011 to 2014, the monthly temperature obviously increased. This could increase potential evaporation and then the actual evaporation, which is not related to vegetation change.

Response: Yes, meteorological condition is indeed an important factor affecting ET. In our study, we have considered the influence of meteorological condition on ET. However, our unclear statements in the section of method may make the reviewers confused. Therefore, we have rewritten the section of method (2.3.3). Please see lines 205-218 and the following explanations.

In this study, we used a simple equation to consider the controlling factors (the potential evapotranspiration (E_{TP}), vegetation condition ($f_v(vegetation)$) and soil water condition ($f_s(soil\,water)$) on ET. Among these factors, potential evapotranspiration is a measure of atmospheric water demand and includes the meteorological conditions. This equation is similar to the FAO single crop coefficient method (Irrigation and Drainage Paper No. 56 (FAO-56)) and is expressed as,

$$\mathrm{ET} = E_{TP} \times f_v(vegetation) \times f_s(soil\,water) \quad (1)$$

where $f_v(\mathrm{vegetation})$ represents the effects of vegetation change on ET, and $f_s(\mathrm{soil\,water})$ represents the effects of soil water content on ET. In order to analyze the control of vegetation change on ET, we excluded the other two influencing factors. Therefore, a transformation of Eq.1 was proposed to be regarded as normalized ET, and it can be expressed as the following formulation,

$$f_v(\mathrm{vegetation}) = \mathrm{E_T}/[\mathrm{E_{TP}} \times f_s(\mathrm{soil\,water})] \quad (2)$$

Thus, we used the normalized ET to study the impacts of vegetation change on ET.

Additionally, Figure 2 shows that the bare soil might be tilled in 2014, which could release more soil moisture as well. The difference between original bare soil and tilled bare soil should not be neglected.

Response: During the three study periods from July 1st 2011 to June 30th 2014, the bare soil is not tilled. We have added the explanations in the revised manuscript. Please see lines 117-118.

For the second conclusion, I suppose this statement is not quite clear. If the authors would like to discuss the total amount evaporation from soil is larger than the total amount of transpiration from canopy. I would agree with that. Because bare soil/sparse shrubland is the dominated land cover in this arid study site. If this is true, I do not see any relationship between this statement and the influence of land cover change on evapotranspiration. If the authors intended to say that the soil evaporation of each unit area is larger than the transpiration from each unit area covered by canopy. Firstly, the other influence factors should be excluded before doing analysis. More importantly, I suggest the authors explain the possible physical mechanism of this phenomena.

Response: Our study intended to say that the soil evaporation of each unit area is larger than the transpiration from each unit. When the area of land use change was ΔS, normalized soil evaporation and transpiration changed $+\Delta E_N$ and $-\Delta T_N$, respectively. The normalized evapotranspiration changed ΔET_N and was the sum of $+\Delta E_N$ and $-\Delta T_N$. We found ΔET_N increased during the three study periods, indicating that $|+\Delta E_N|$ was more than $|-\Delta T_N|$. Therefore, the normalized soil evaporation from each unit ($|+\Delta E_N|/\Delta S$) was larger than transpiration from each unit ($|-\Delta T_N|/\Delta S$). Due to the unclear statements in the Discussion part (4.2), we have revised the Discussion part to make our conclusion more clear. Please see lines 486-488.

We have excluded the impacts of other influencing factors on ET before the analysis. Our unclear statements of the method may make the reviewers confused, so we have rewritten the Method part (2.3.3). Please see lines 205-218.

Since this does not quite match with our knowledge on evaporation that soil evaporation can only consume soil moisture in top layer; while vegetation can consume soil moisture in deeper root zone layers, especially in this arid area where the rooting depth could be over 1m. I would like to ask the authors to do more discussion on this issue.

Response: Our conclusions are the same as the reviewer's. We thought the vague description of vegetation in the "site description" part may make the reviewer confused. Therefore, we added the following statements into the "site description" part, please see lines 102-105.

"The vertical roots were surveyed to be mainly (90%) distributed within 100 cm (Yang, 2012), and they absorb the water from shallow soil of 60-80 cm (Liu et al., 2010; Yang, 2012)."

Thirdly, I am quite confused with the discussion on impacts of phonological change on ET and effects of land use change on ET. The authors mentioned that ET has positive relationship with NDVI on the influence of vegetation phonology. This indicates that the better vegetation it is, the larger ET it is in different seasons. Simultaneously, the authors mentioned that after the vegetation cut-off, annual ET increased. I would like to authors clarify this 'contradiction'.

Response: In our study, vegetation phenology was represented by Moderate Resolution Imaging Spectroradiometer (MODIS)-NDVI data when land use type was constant (lines 269-270). Vegetation cut-off represented the land use change, converting the vegetation to bare soil (lines 113-114). The phenological change and land use change have essentially different mechanisms on affecting ET. Therefore, the effects of variations in NDVI and vegetation cut-off are not contradictory. Due to the unclear expressions which may be confusing, we have revised some statements of Method, Results and Discussion parts to make our conclusions more clear. Please see lines 269-270, 287-301, 350-354, 364-370, 398-400, 423-429, 446-448, 459-461, 486-488 and the following detailed explanations.

In our study, we used the data of 2011-2012 to analyze the impact of phenological change on normalized ET, because in this period, the vegetation type was stable and there was not any land use change happened (lines 398-400). Seasonal NDVI during this year could reflect the vegetation phenology (lines 269-270), such as when the vegetation entered the growing season and so on (lines 350-354). In this case, normalized ET increased along with the vegetation greening (lines 423-429). The mechanism of this increase of normalized ET is due to the increase of leaf stomata, and more transpiration will be transferred to the atmosphere (lines 459-461).

However, the land use change represented the conversion of vegetation type and in our study, this conversion was from natural vegetation to bare soil. To discuss the impact of land use change on normalized ET, we firstly treated the land use condition of zone A (the area that has not encountered the land use change) as the reference, and the differences of vegetation coverage between zone A and zone B ($D_{\mathrm{lu}}=M_A-M_B$) as the measure of land use change (lines 287-301). D_{lu} represents land use change most exactly in summer than in winter, because M is a measure of the fraction of green vegetation and D_{lu} in winter is meaningless and nearly zero. So we selected D_{lu} of July—September in each period as the measure of land use change (lines 364-370, Fig.1). We found that with land use change, the normalized ET increased (lines 446-480, 486-488, Fig.2). The mechanism of this increase ET is that the soil evaporation from each unit of increased bare soil is larger than transpiration from each unit.

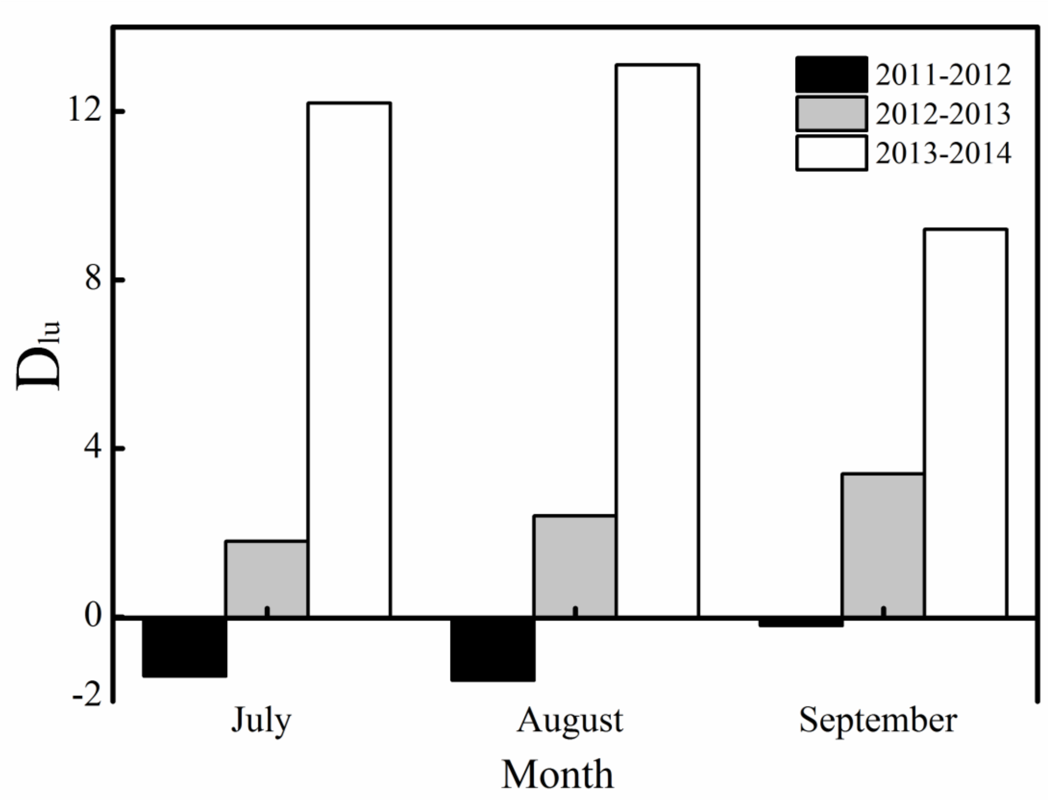

Figure 1 The D_{lu} of July, August and September in each period.

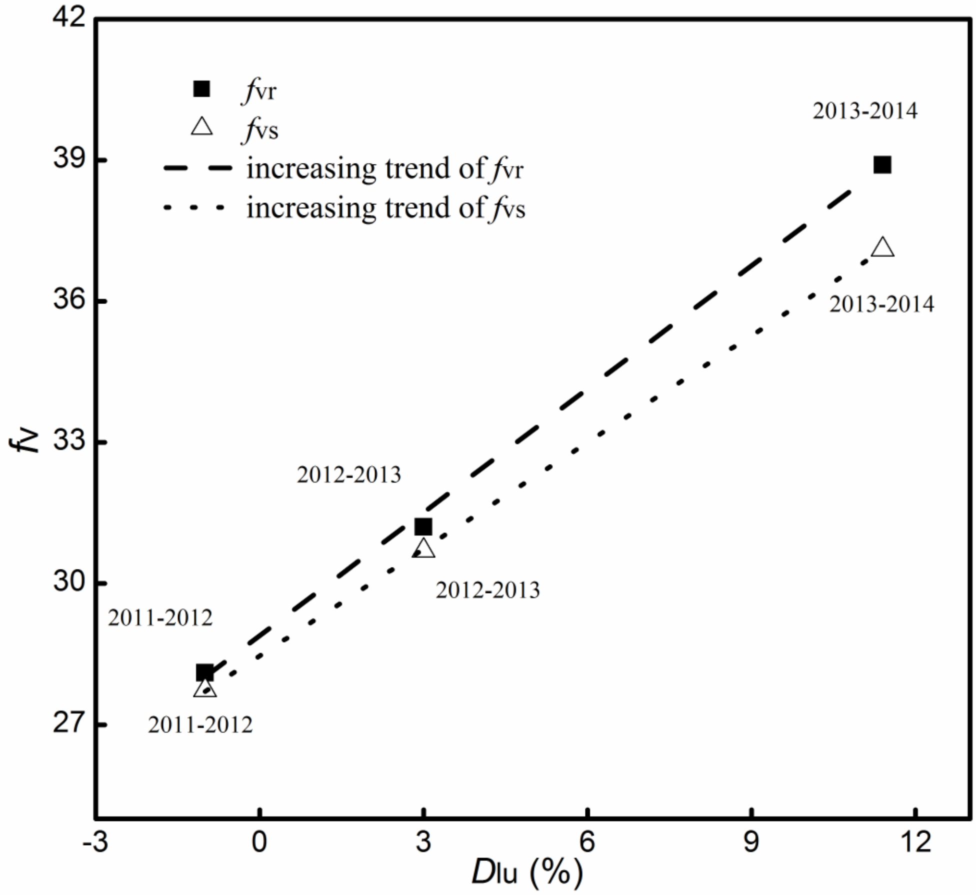

Figure 2 Quantitative analysis between D_{lu} by human activities and ET ($f_{\mathrm{vr}} = ET/(E_{\mathrm{TP}} \times f_{\mathrm{sr}})$, $f_{\mathrm{vs}} = ET/(E_{\mathrm{TP}} \times f_{\mathrm{ss}})$) in July—September of each period.

Small comments:

P13572 (P72 hereinafter), L20: '. . .consumed by ET. . .', references are needed.

Response: We have added the references. Please see line 31.

P73, L17: references are needed.

Response: We have added the references. Please see line 57.

P80: Equation 7. It might be theta>thetak in the first line.

Response: We have corrected it.

References:

Jin, T. The growing research of *Salix psammophila* in the Mu Us sandy land. Practical Forestry Technolgy, 01, 7-9, 2009.

Liu, J., He, X., Bao, H. L. and Zhou C. J.. Distribution of fine roots of salix psammophila and its relationship with soil moisture in Mu Us Sand land. Journal of Desert Research, 30, 1362-1366, 2010.

Yang, F.. A study of the vadose zone water movement's law under the influence of vegetation—a case of the Mu Us Sand land. Chang'an University, Xi'an, China, 2012.

3 Responses to the Reviewer #2

4 Responses to the Reviewer #2

Main remarks:

The manuscript attempts to quantify the effects of land use change and vegetation phenological change on evapotranspiration in a shrubland ecosystem in China using eddy covariance measurements. Evapotranspiration is a critical ecosystem variable but the controls on ET and particularly its interaction with vegetation processes remain relatively poorly quantified. As the authors point out, ET changes are critical for water resources in dry regions and as such the study addresses an important aspect of coupled hydrological and land surface processes.
However, despite much effort in analyzing the data, the authors do not clearly explain their findings and present somewhat conflicting conclusions. The authors state seasonal vegetation greening increases ET but so does the clearing of natural vegetation. In particular, the reported increase in ET due to land clearing is somewhat counterintuitive. However, the authors need to discuss this in more detail to propose specific mechanisms for why this would be the case in their study site. More generally, the authors need to clarify why vegetation is the main control on ET if ET at the study site is dominated by soil evaporation and why both seasonal greening and vegetation clearance appear to increase ET.

Response: The conclusions are actually not contradictory, because the mechanisms of these two conclusions are different. Due to the unclear statements of Method part and less explanations of Results and Discussion part that may be confusing, we have rewritten the Method part (2.3.3) and Results (3.3 and 3.4) and Discussion part (4.1 and 4.2).Please see lines 269-270, 287-300, 349-353, 364-371, 400-401, 424-430, 445-450, 459-461, 488-490 and the following detailed explanations.

The first conclusion was that normalized ET increased along with the vegetation greening. We demonstrated this conclusion by using the data of 2011-2012 (lines 400-401), since in this period, the vegetation type was stable and there was not any land use change. Seasonal NDVI during 2011-2012 could reflect the vegetation phenology (lines 269-270), such as when the vegetation entered the growing season and so on (349-353). In this case, normalized ET increased along with the vegetation greening (lines 424-430). The mechanism of this increase of normalized

ET is due to the increase of leaf stomata, and more water will be transpired to the atmosphere during the vegetation greening and growing process (lines 449-461).

The second conclusion was found in the case of land use change. Land use change represented the conversion of vegetation type, and in this study, this conversion was from vegetation to bare soil. To discuss the impact of land use change on normalized ET, we treated the land use condition of zone A (land use condition was not changed) as the reference, and the differences of vegetation coverage between zone A and zone B ($D_{lu}=M_A-M_B$) as the measure of land use change (lines 287-300). D_{lu} represents land use change most exactly in summer than in winter, because M is a measure of the fraction of green vegetation and D_{lu} in winter is meaningless. So we selected D_{lu} of July—September in each period as the measure of land use change (lines 364-371, Fig.1). We found that with land use change, the normalized ET increased (lines 445-450, 488-490, Fig.2). When the area of land use change was ΔS, normalized soil evaporation and transpiration changed $+\Delta E_N$ and $-\Delta T_N$, respectively. The normalized evapotranspiration changed ΔET_N and was the sum of $+\Delta E_N$ and $-\Delta T_N$. We found ΔET_N increased during the three study periods, indicating that $|+\Delta E_N|$ was more than $|-\Delta T_N|$. Therefore, the normalized soil evaporation from each unit ($|+\Delta E_N|/\Delta S$) was larger than transpiration from each unit ($|-\Delta T_N|/\Delta S$). Therefore, the mechanism of this increase of normalized ET is that the normalized soil evaporation from each unit of increased bare soil is larger than normalized transpiration from each unit.

Therefore, our results imply that when vegetation type is table, vegetation phenology is the main control factor on the seasonal variation in ET. However, when land use changed from vegetation to bare soil, much larger of soil evaporation from each unit of increased bare soil than transpiration may also make the ET increase.

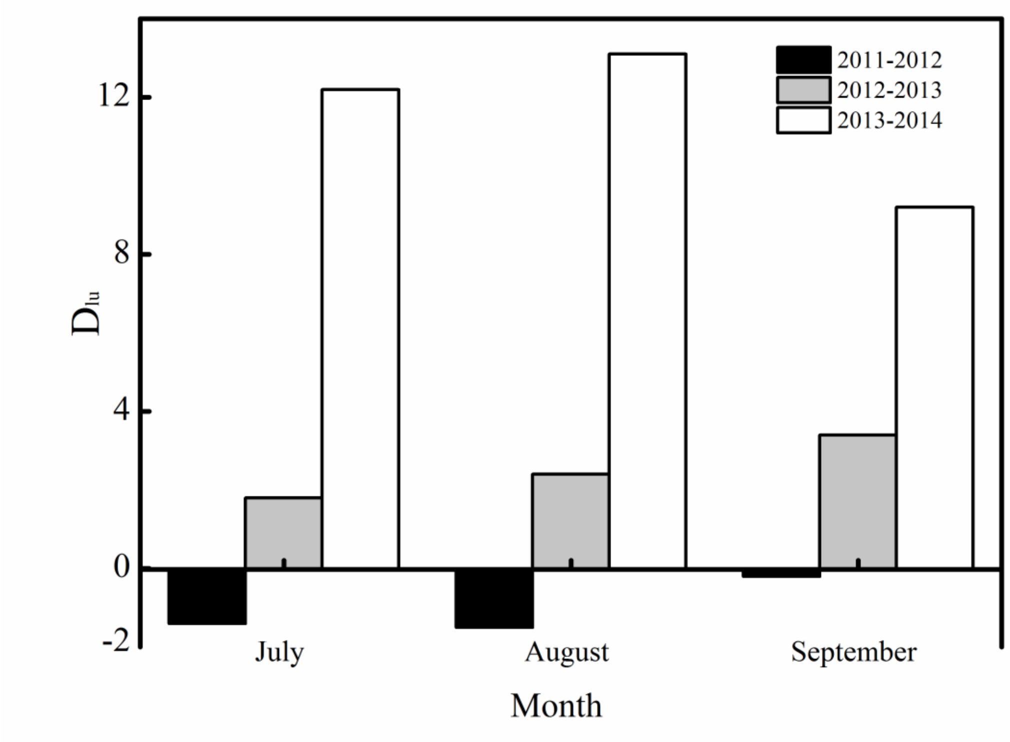

Figure 1 The D_{lu} of July, August and September in each period.

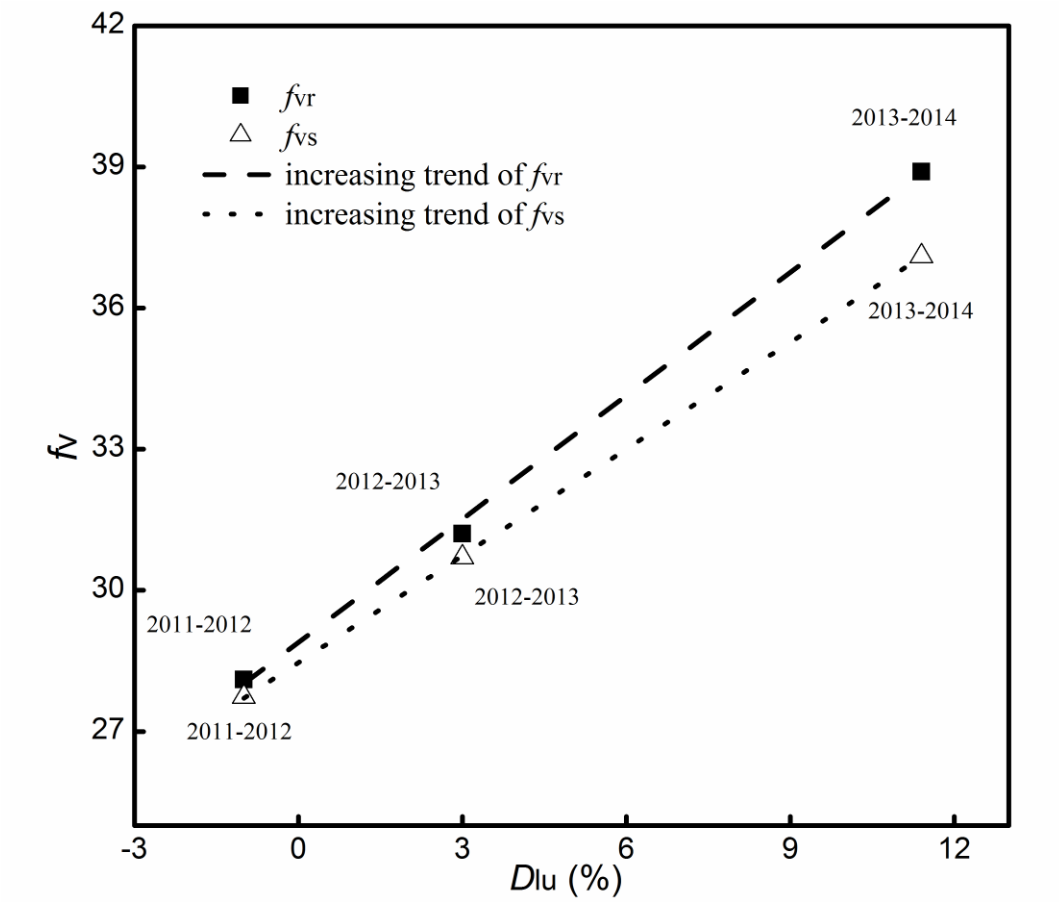

Figure 2 Quantitative analysis between D_{lu} by human activities and ET ($f_{vr} = ET/(E_{TP} \times f_{sr})$, $f_{vs} = ET/(E_{TP} \times f_{ss})$) in July—September of each period.

Studies generally report a decrease in ET when vegetation is cleared or reduced (e.g. Bosch and Hewlett, 1982; Gordon et al., 2005) due to declining transpiration. Furthermore, transpiration usually forms the greater proportion of total ET and as such declines in vegetation would likely reduce total ET.

Response: We agree with the reviewer's comments about the decrease of ET when land clearing happened. But we think this phenomenon is applied to the much higher dense vegetated ecosystems such as forests and grasslands. Just as the reviewer said, in these higher dense vegetated ecosystems, transpiration takes greater proportion than soil evaporation. Some other researchers have also demonstrated this conclusion (Huang et al., 2010; Hu et al., 2013; Wang and Yakir, 2000).

However, in the sparse vegetated ecosystems such as our study site with the xeric vegetation, some studies have also demonstrated that soil evaporation was more than transpiration (Kurc and Small, 2004; Zhang et al., 2005).

We have added the aforesaid statements into the revised manuscript. Please see lines 490-495.

Clearing of vegetation should also lead to reduced access to groundwater, diminishing water supply for ET and resulting in decreased ET in a water-limited area such as the study site.

Response: The groundwater is not accessible by the vegetation roots at our site. Because the maximum root depth of vegetation was measured as less than 160 cm, and the mean groundwater level was 3.4 m. Therefore, we considered the impact (f_{sr}) of soil water content of root zone on ET, and it is expressed as (lines 241-245),

$$f_{sr} = \begin{cases} = 1 & \theta_r > \theta_k \\ = 0 & \theta_r < \theta_w \\ = \frac{\theta_r - \theta_{\mathrm{w}}}{\theta_{\mathrm{k}} - \theta_{\mathrm{w}}} & \theta_w \le \theta_r \le \theta_k \end{cases} \tag{1}$$

Before we compared the normalized ET of three periods, we have excluded the impact of f_{sr} on ET (lines 206-218).

We agree with the reviewer's comments. When the vegetation of our study site was cut-off, transpiration decreased, but soil evaporation increased more than the transpiration decreased, so we found evapotranspiration increased.

Minor comments

P13575 L12: What do you mean by "vegetation coverage"? Foliage fractional cover or something else?

Response: In our study, vegetation coverage is regarded as the fraction of green vegetation (Gutman and Ignatov, 1998).

P13576 L5: The FLUXNET network now comprises of 650 towers (fluxnet.ornl.gov/), the authors should consider replacing "several" sites.

Response: we have replaced the "several" as "a number of". Please see line 131.

P13579 L9-15: Why was this particular potential evapotranspiration (PET) formulation chosen? PET is a key variable in the study to estimate actual ET and as many equations for PET exist, the authors should clearly justify the choice of PET formulation. The equation appears (near) identical to the Penman formulation (Penman, 1948) but this is not clear from the text.

Response: Yes, this formulation is a transformation from Penman formulation. The differences are the estimations of the aerodynamic resistances (r_a) and the aerodynamic roughness of surface (Z_0). The form of the aerodynamic resistances (r_a) was estimated as the following formulation (Penman, 1948 and 1963),

$$r_a(\mathrm{s/m}) = \frac{4.72[ln(\frac{Z_m}{Z_0})][ln(\frac{Z_m}{Z_0})]}{1+0.536U_2} \tag{2}$$

where Z_m is the height at which meteorological variables are measured (2 m), and Z_0 is the aerodynamic roughness of surface (0.00137 m)

We have added these explanations into the revised manuscript. Please see lines 218-232.

P13579 L18-20: Why was MODIS Terra chosen? The Terra satellite is known to have suffered from sensor degradation in recent years (e.g. Wang et al., 2012), including the current study period. Why was MODIS Aqua data not used or a combination of the two sensors to overcome data quality issues (e.g. cloud) and Terra limitations?

Response: We actually downloaded the MODIS/Terra and MODIS/Aqua surface reflectance data from the reverb (http://reverb.echo.nasa.gov). We found there were not obvious differences between these two data series in our study site (Fig.3), so we just select MODIS/Terra surface reflectance data to use. Now that according to the reviewer's suggestion, therefore, in the revised manuscript (lines 272-274, 285-286), we calculated the daily mean NDVI by the mean of MODIS/Terra and MODIS/Aqua, which was expressed by the following equation,

$$NDVI = \frac{NDVI_{Terra} + NDVI_{Aqua}}{2} \quad (3)$$

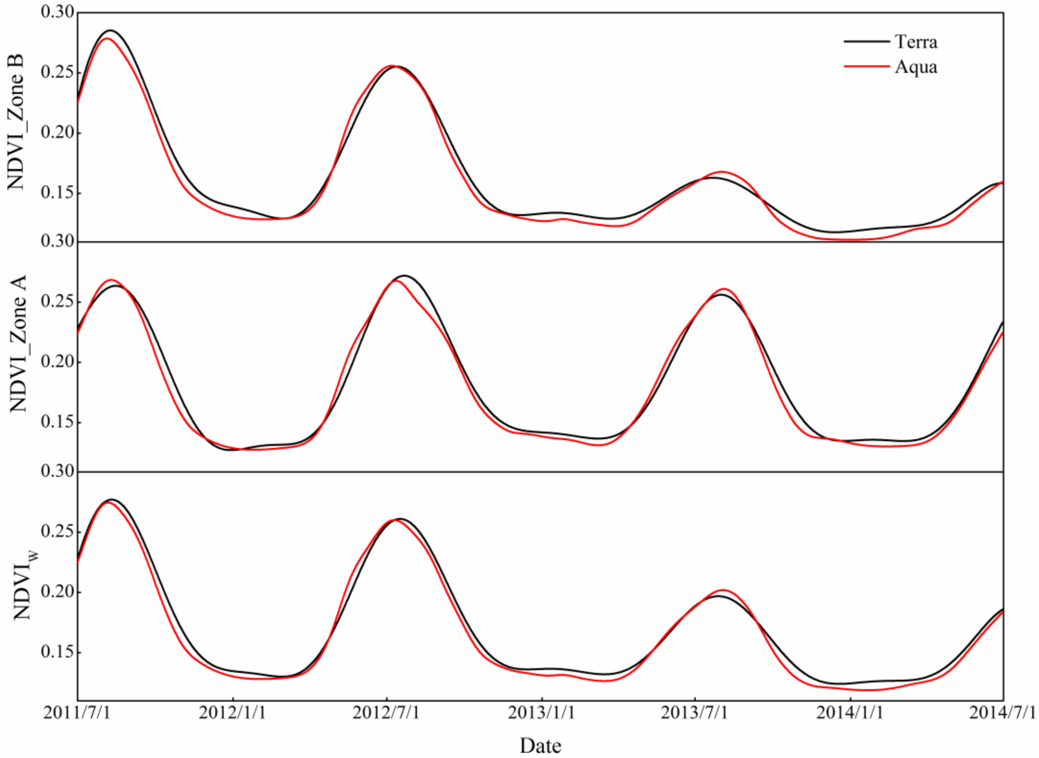

Figure 3 Comparisons of MODIS/Terra and MODIS/Aqua NDVI of zone A, zone B and weight-averaged within the whole footprint.

P13582 L5-9: This information should be stated in the figure caption, not the main text.

Response: We have removed the information from the main text, and stated in the figure caption.

Please see line 733-737.

P13582 L11-12: The authors state the area of zone B changed over time but was fixed in the study. Was the mean or maximum extent of cleared area used for analysis and how much did the area vary?

Response: In our study, the area of zone B was the maximum extent of land clearing. Because we measured the boundary of land clearing zone (zone B) until October 2013, when the land use condition of zone B has stopped to change. We have added these statements into the revised manuscript. Please see lines 310-311.

Land clearing happened in zone B while land use condition of zone A was not changed during the three periods. Therefore, we came up with a method to obtain the process of land use change. We regarded the vegetation coverage of zone A as reference, and introduced an indicator of D_{lu} to be the measure of land use change, which was calculated by the differences of vegetation coverage (M_A-M_B) between the reference and zone B. D_{lu} represents the land use change most exactly in summer than in winter, because M is a measure of the fraction of green vegetation and D_{lu} in winter is meaningless and nearly zero (lines 297-298). So we selected the mean D_{lu} of July—September in each period to analyze the impacts of land use change on normalized ET (lines 299-300, 364-371). The results are shown in the following Fig.4. Compared to 2011-2012, D_{lu} of 2012-2013 and 2013-2014 both increased. Taking August of each period as example, in August of 2011-2012, D_{lu} was -1.5% due to the tiny differences in spatial distributions of natural vegetation, while in August of 2012-2013 and 2013-2014, D_{lu} were 2.4% and 13.1%, respectively. This phenomenon represented that compared to the August of 2011-2012, the percentage of land use change of 2012-2013 and 2013-2014 increased 4.5% and 14.6%, respectively.

Therefore, despite we did not measure the exact land use changing process of zone B, our method can reflect this process as well. Vague statements in the Method part may make the reviewer confused, so we have rewritten the Method part to state our method more clearly. Please see lines 287-300.

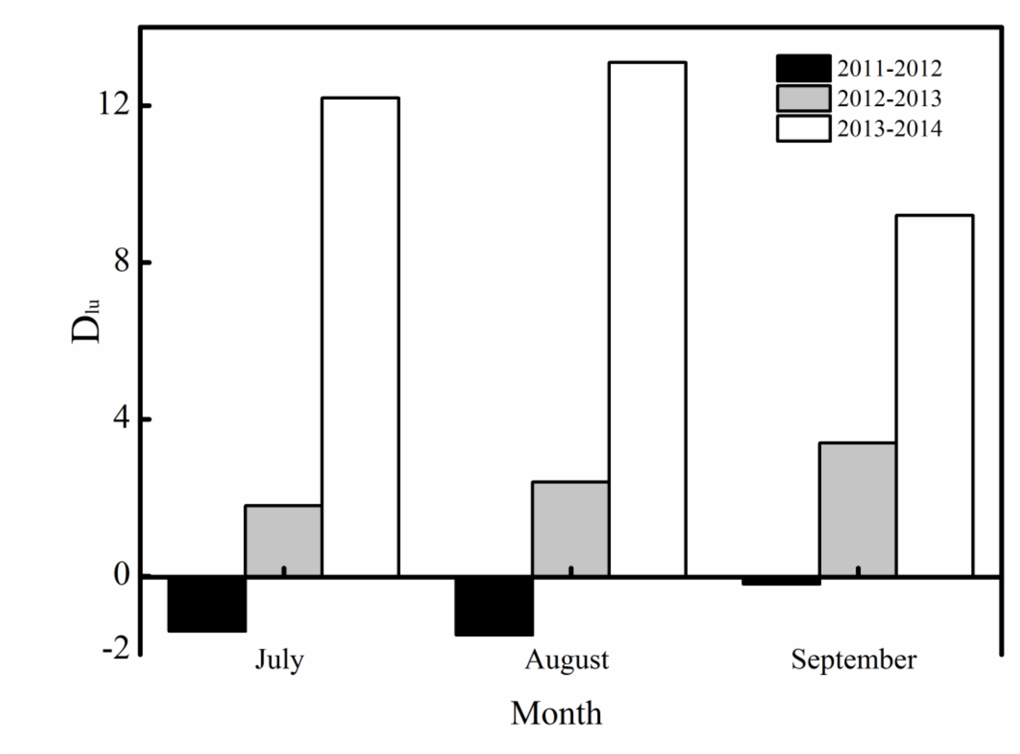

Figure 4 The D_{lu} of July, August and September in each period.

P13584 L26: I don't think Ss and Sr are defined anywhere in the main text.

Response: We have added the definition in the revised manuscript, and revisions are marked as red in 2.3.3. Please see lines 241-245. In the revised manuscript, we have replaced the S by f_s to reflect the impact of soil water content on ET.

In this study, f_{sr} and f_{ss} were defined as impacts of soil water content of root zone and surface on ET, respectively, and were calculated as the following formulations

$$f_{sr} = \frac{\theta_r - \theta_w}{\theta_k - \theta_w} \quad (\theta_w \le \theta_r \le \theta_k) \tag{3}$$

$$f_{ss} = \frac{\theta_s - \theta_w}{\theta_k - \theta_w} \quad (\theta_w \le \theta_s \le \theta_k) \tag{4}$$

P13585 L21-23: The normalization parameter appears to be an important method for attributing ET changes to specific drivers; a clearer explanation for what it represents and why it is adopted would be useful. The meaning of the parameter is not immediately clear (to the reviewer at least) and the authors should spend more time explaining the method.

Response: We have rewritten the Method part (2.3.3) to make it clear. We have changed the "normalized parameter" to "normalized ET" in the revised manuscript, making our conclusions more clear.

The normalization ET in our study represented the effects of vegetation change on ET (lines

216-217).

The reason for why we adopted the normalization method is that we need to eliminate the effects of meteorological condition and soil water condition (lines 206-218), in order to discuss the impact of vegetation change on ET. So we transformed the Eq.3 (line 212) by dividing PET and f_s from ET (lines 214-217).

P13587 L7: What is the unit of increase?

Response: The unit of increase was mm. We have added the unit in the revised manuscript. Please see line 449-450.

P13588 L16-20: The two sentences appear to contradict each other. On one hand, the authors state vegetation cover *above* a certain threshold can increase ET but on the other, vegetation cover *under* a threshold can also increase ET.

Response: After thinking about the reviewer's comments, we found we have misunderstood the meaning of this finding of Li et al. (2009). Thus, we removed the sentences from our revised manuscript.

Figure 3 caption: Needs clarification and further details on what the different lines and symbols represent.

Response: We have added more expressions below the figure 3 caption. Please see line 733-737.

In Fig.3 caption of the revised manuscript, we revised and added the following explanations: "the black line of Fig.3b is the simulated footprint; the long axis is 1682m, and the short axis is 1263m; the background is the MODIS Surface Reflectance (250 m × 250 m) on 3 January 2011. Square white dots were measured points on 25 October 2013, and the white line is the maximum boundary of bare soil area"

Figure 9 caption: In the main text *M* signifies monthly mean vegetation coverage but in the figure caption is represents "land use change". This is somewhat confusing. Parts of the manuscript are poorly written and hard to follow, for example (but not exclusively) P13572 L8-10, P13588 L4-5 and Discussion in general.

Response: we thought the unclear statements of Method part may make the reviewer confused, therefore, we have rewritten the Method part (2.3.3). Please see lines 287-300.

We have revised the caption of Fig.9 with the following statements: "Quantitative analysis between D_{lu} and normalized ET ($f_{vr} = ET/(E_{TP} \times f_{sr})$, $f_{vs} = ET/(E_{TP} \times f_{ss})$) in July－September of each period". Please see lines 769-770.

According to the reviewer's comments and suggestions, we have revised this manuscript substantially to make our conclusions more clear. All revisions are marked as red in the revised manuscript. Please find the revised manuscript in the attachment.

Technical corrections

13572 L1: grammatical error.

Response: We have revised the first sentence in the abstract part.

The new sentence is “Evapotranspiration (ET) is an important process in the hydrological cycle, and vegetation change is a primary factor that affects ET”. Please see line lines 10-11.

13573 L19: typo.

Response: We have revised the ‘penological’ to ‘phenological’ in the revised version of manuscript. Please see line 58.

References:

Hu, G., et al., Driving forces of aeolian desertification in the source region of the Yellow River: 1975–2005. Environmental Earth Sciences, 2013. 70(7): p. 3245-3254.

Huang, M., et al., Actual evapotranspiration estimation for different land use and land cover in urban regions using Landsat 5 data. Journal of Applied Remote Sensing, 2010. 4(1): p. 041873-041873-14.

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Wang, X.F. and D. Yakir, Using stable isotopes of water in evapotranspiration studies. Hydrological Processes, 2000. 14(8): p. 1407-1421.

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